

Mild and facile synthesis of Formamide: Reduction and functionalization of CO₂ using NaBH(OAc)₃ under atmospheric pressure

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General information

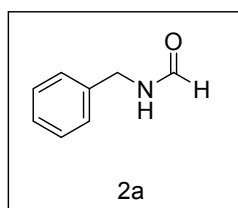
Purification of reaction products were carried out by chromatography using silica gel (200 - 300 mesh). Melting points were recorded on a BüCHI B-540 melting point apparatus. NMR spectra were recorded for ^1H NMR at 500 MHz. For ^1H NMR, tetramethylsilane (TMS) served as internal standard ($\delta = 0$) and data are reported as follows: chemical shift, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, br=broad), coupling constant in Hz and integration. HRMS data were obtained on an Agilent 1290 HPLC-6224 Time of Flight Mass Spectrometer. Unless otherwise noted, all reagents were obtained commercially and used without further purification.

General procedure for preparing N-formylated amines

Amine (1 mmol, 1.0 equiv.) was dissolved in 6 mL acetonitrile along with 0.64 g $\text{NaBH}(\text{OAc})_3$ (3 mmol, 3.0 equiv.). The reaction mixture was then stirred at 50 °C under an atmosphere of CO_2 (99.999%) for 5 hours. After cooling the system to room temperature, the CH_3CN was removed under reduced pressure and the residue was extracted with 10 mL ethyl acetate twice. Then the solution was concentrated and purified by silica gel column chromatography (PE/EA).

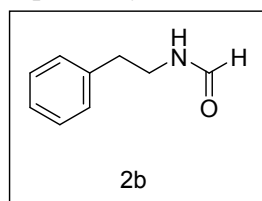
Compound characterization

N-benzylformamide: CAS registry No. 6343-54-0



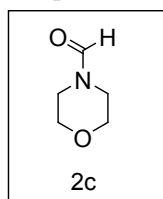
White solid; mp: 55.4~57.0 °C; ^1H NMR (500 MHz, CDCl_3) δ 8.27 (s, 1H), 7.37-7.28 (m, 5H), 5.84 (s, 1H), 4.49 (d, $J = 5.5$ Hz, 2H). HRMS (ESI): m/z calcd for $\text{C}_8\text{H}_9\text{NO}$ $[\text{M}+\text{H}]^+$: 136.0757, found: 136.0761

N-phenethylformamide: CAS registry No. 23069-99-0



Yellow oil; ^1H NMR (500 MHz, DMSO-d_6) δ 8.06 (s, 1H), 7.99 (s, 1H), 7.32-7.26 (m, 2H), 7.23-7.19 (m, 1H), 3.32 (q, $J = 6.5$ Hz, 2H), 2.72 (t, $J = 7.5$ Hz, 2H). HRMS (ESI): m/z calcd for $\text{C}_9\text{H}_{11}\text{NO}$ $[\text{M}+\text{H}]^+$: 150.0913, found: 150.0918

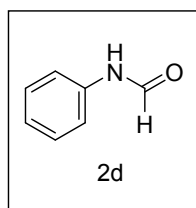
morpholine-4-carbaldehyde: CAS registry No. 4394-85-8



Colorless liquid; ^1H NMR (500 MHz, CDCl_3) δ 8.04 (s, 1H), 3.68 (t, $J = 5.0$ Hz, 2H), 3.65 (t, $J =$

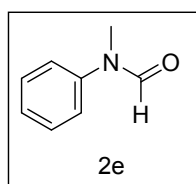
5.0 Hz, 2H), 3.56 (t, $J = 5.0$ Hz, 2H), 3.39 (t, $J = 5.0$ Hz, 2H). HRMS (ESI): m/z calcd for $C_5H_9NO_2$ $[M+H]^+$: 116.0706, found: 116.0709

N-phenylformamide: CAS registry No. 103-70-8



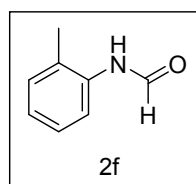
Light yellow oil; 1H NMR (500 MHz, $CDCl_3$) (trans/cis=1/1) δ 8.79 (s, 1H), 8.70 (d, $J = 11.5$ Hz, 1H), 8.36 (d, $J = 2.0$ Hz, 1H), 7.78 (s, 1H), 7.58-7.52 (m, 2H), 7.40 – 7.30 (m, 5H), 7.21-7.17 (m, 1H), 7.16-7.09 (m, 4H). HRMS (ESI): m/z calcd for C_7H_7NO $[M+H]^+$: 122.0600, found: 122.0603

N-methyl-N-phenylformamide: CAS registry No. 93-61-8



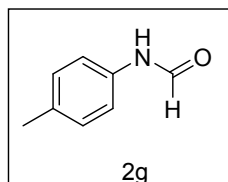
Yellow oil; 1H NMR (500 MHz, $CDCl_3$) δ 8.47 (s, 1H), 7.41 (t, $J = 7.5$ Hz, 2H), 7.28 (t, $J = 7.5$ Hz, 1H), 7.17 (d, $J = 7.5$ Hz, 2H), 3.32 (s, 3H). HRMS (ESI): m/z calcd for C_8H_9NO $[M+H]^+$: 136.0757, found: 136.0767

N-o-tolylformamide: CAS registry No. 94-69-9



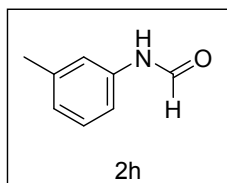
White solid; mp: 67.4~69.0 °C; 1H NMR (500 MHz, $DMSO-d_6$) (trans/cis=2/5) δ 9.67 (d, $J = 11.0$ Hz, 0.4H), 9.51 (s, 1H), 8.41 (d, $J = 11.0$ Hz, 0.4 H), 8.29 (d, $J = 2.0$ Hz, 1H), 7.73 (d, $J = 10.0$ Hz, 1H), 7.24-7.02 (m, 5H), 2.24 (s, 1.2H), 2.22 (s, 3H). HRMS (ESI): m/z calcd for C_8H_9NO $[M+H]^+$: 136.0757, found: 136.0760

N-p-tolylformamide: CAS registry No. 3085-54-9



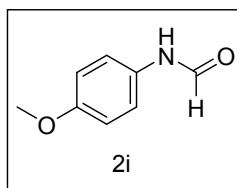
Brown solid; mp: 56.4~58.0 °C; 1H NMR (500 MHz, $CDCl_3$) (trans/cis=6/5) δ 8.62 (d, $J = 11.5$ Hz, 1H), 8.34 (d, $J = 2.0$ Hz, 1H), 8.20 (s, 1H), 7.42 (d, $J = 8.0$ Hz, 2H), 7.18-7.11 (m, 4H), 6.98 (d, $J = 8.0$ Hz, 2H), 2.33 (s, 3H), 2.32 (s, 2.5H). HRMS (ESI): m/z calcd for C_8H_9NO $[M+H]^+$: 136.0757, found: 136.0756

N-m-tolylformamide: CAS registry No. 3085-53-8



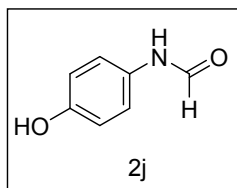
Yellow oil; $^1\text{H NMR}$ (500 MHz, DMSO-d_6) (trans/cis=2/5) δ 10.04 (s, 1.4H), 8.76 (d, $J = 11.0$ Hz, 0.4H), 8.25 (d, $J = 2.0$ Hz, 1H), 7.41 (s, 1H), 7.39-7.35 (m, 1H), 7.19 (t, $J = 8.0$ Hz, 1.5H), 7.02-6.96 (m, 0.8H), 6.91-6.86 (m, 1.4H), 2.27 (s, 4.3H). HRMS (ESI): m/z calcd for $\text{C}_8\text{H}_9\text{NO}$ $[\text{M}+\text{H}]^+$: 136.0757, found: 136.0764

N-(4-methoxyphenyl)formamide: CAS registry No. 5470-34-8



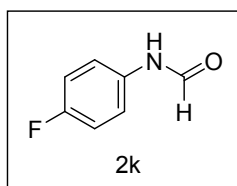
Yellow solid; mp: 81.2~82.5 $^\circ\text{C}$; $^1\text{H NMR}$ (500 MHz, CDCl_3) (trans/cis=1/1) δ 8.50 (d, $J = 11.5$ Hz, 1H), 8.32 (s, 1H), 8.20-7.83 (br, 1H), 7.44 (d, $J = 9.0$ Hz, 2H), 7.03 (d, $J = 9.0$ Hz, 2H), 6.92 – 6.83 (m, 4H), 3.80 (s, 3H), 3.79 (s, 3H). HRMS (ESI): m/z calcd for $\text{C}_8\text{H}_9\text{NO}_2$ $[\text{M}+\text{H}]^+$: 152.0706, found: 152.0707

N-(4-hydroxyphenyl)formamide: CAS registry No. 1693-39-6



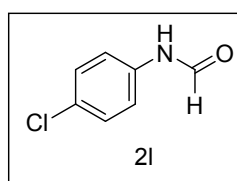
Brown solid; mp: 134.7-136.4 $^\circ\text{C}$; $^1\text{H NMR}$ (500 MHz, DMSO-d_6) (trans/cis=1/3) δ 9.90 (s, 0.75H), 9.84 (d, $J = 11.5$ Hz, 0.25H), 9.24 (s, 1H), 8.50 (d, $J = 11.0$ Hz, 0.25H), 8.34 (s, 0.39H), 8.15 (d, $J = 2.0$ Hz, 0.77H), 7.43-7.25 (m, 1.5H), 7.02-6.93 (m, 0.5H), 6.76-6.64 (m, 2H), 6.52-6.35 (m, 2H). HRMS (ESI): m/z calcd for $\text{C}_7\text{H}_7\text{NO}_2$ $[\text{M}+\text{H}]^+$: 138.0550, found: 138.0554

N-(4-fluorophenyl)formamide: CAS registry No. 459-25-6



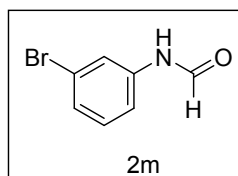
Brown solid; mp: 67.2-69.0 $^\circ\text{C}$; $^1\text{H NMR}$ (500 MHz, CDCl_3) (trans/cis=9/10) δ 8.56 (d, $J = 11.5$ Hz, 0.9H), 8.48 (br, 0.7H), 8.35 (d, $J = 2.0$ Hz, 1H), 7.55-7.47 (m, 2.1H), 7.43 (br, 0.9H), 7.10-6.97 (m, 5.3H). HRMS (ESI): m/z calcd for $\text{C}_7\text{H}_6\text{FNO}$ $[\text{M}+\text{H}]^+$: 140.0506, found: 140.0504

N-(4-chlorophenyl)formamide: CAS registry No. 2617-79-0



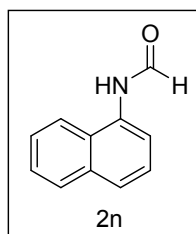
White solid; mp: 102.4~103.8 °C; ¹H NMR (500 MHz, CDCl₃) (trans/cis=4/5) δ 8.65 (d, *J* = 11.0 Hz, 0.8H), 8.60 (s, 1H), 8.36 (br, 0.6H), 7.64 (br, 0.9H), 7.49 (d, *J* = 6.5 Hz, 2H), 7.34-7.25 (m, 3.6H), 7.04 (d, *J* = 8.5 Hz, 1.4H). HRMS (ESI): *m/z* calcd for C₇H₆ClNO [M+H]⁺: 156.0211, found: 156.0214

N-(3-bromophenyl)formamide: CAS registry No. 37831-25-7



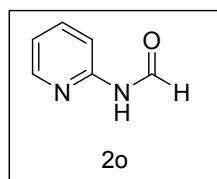
Yellow oil; ¹H NMR (500 MHz, DMSO-*d*₆) (trans/cis=1/1) δ 10.32 (s, 1H), 10.19 (d, *J* = 11.0 Hz, 0.3H), 8.83 (d, *J* = 11.0 Hz, 0.3H), 8.30 (d, *J* = 2.0 Hz, 1H), 7.93 (t, *J* = 2.0 Hz, 1H), 7.49 (dt, *J* = 7.5, 2.0 Hz, 1H), 7.43 (s, 0.3H), 7.30-7.19 (m, 3H). HRMS (ESI): *m/z* calcd for C₇H₆BrNO [M+H]⁺: 199.9706, found: 199.9695

N-(naphthalen-1-yl)formamide: CAS registry No. 6330-51-4



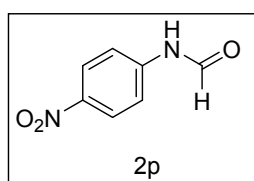
White solid; mp: 135.4~136.0 °C; ¹H NMR (500 MHz, DMSO-*d*₆) (trans/cis=1/2) δ 10.50 (d, *J* = 10.5 Hz, 0.5H), 10.32 (s, 1H), 8.59 (d, *J* = 10.5 Hz, 0.5H), 8.49 (d, *J* = 2.0 Hz, 1H), 8.17-8.09 (m, 1.5H), 8.01 (d, *J* = 8.0 Hz, 1H), 7.97-7.92 (m, 1.5H), 7.80 (d, *J* = 8.5 Hz, 0.5H), 7.74 (d, *J* = 8.5 Hz, 1H), 7.61-7.53 (m, 3H), 7.52-7.47 (m, 1.5H), 7.41 (d, *J* = 7.0 Hz, 0.5H). HRMS (ESI): *m/z* calcd for C₁₁H₉NO [M+H]⁺: 172.0757, found: 172.0761

N-(pyridin-2-yl)formamide: CAS registry No. 34813-97-3



White solid; mp: 72.4~73.0 °C; ¹H NMR (500 MHz, DMSO-*d*₆) (trans/cis=9/2) δ 10.59 (s, 1.8H), 10.46 (s, 0.4H), 9.28 (d, *J* = 10.0 Hz, 1H), 8.36-8.21 (m, 2.7H), 8.06 (d, *J* = 8.5 Hz, 1H), 7.85-7.64 (m, 2H), 7.16-6.97 (m, 2H), 6.92 (d, *J* = 8.5 Hz, 1H). HRMS (ESI): *m/z* calcd for C₆H₆N₂O [M+H]⁺: 123.0553, found: 123.0558

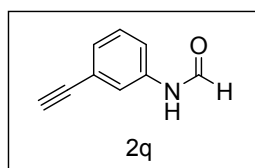
N-(4-nitrophenyl)formamide: CAS registry No. 16135-31-2



Yellow solid; mp: 194.4~196.0 °C; ¹H NMR (500 MHz, DMSO-*d*₆) (trans/cis=3/1) δ 10.81 (s, 1H), 10.70 (d, *J* = 10.0 Hz, 0.3H), 9.05 (d, *J* = 10.3 Hz, 0.3H), 8.40 (s, 1H), 8.27-8.15 (m, 2.66H), 7.82

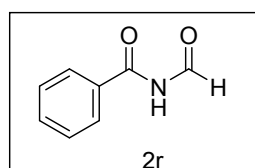
(d, $J = 9.0$ Hz, 2H), 7.42 (d, $J = 9.0$ Hz, 0.6H). HRMS (ESI): m/z calcd for $C_7H_6N_2O_3$ $[M+H]^+$: 167.0451, found: 167.0447

N-(3-ethynylphenyl)formamide: CAS registry No. 1364394-80-8



White solid; mp: 232.4~233.0 °C; 1H NMR (500 MHz, $CDCl_3$) (trans/cis=1/1) δ 8.72-8.68 (m, 1H), 8.37 (d, $J = 2.0$ Hz, 1H), 7.67 (s, 1H), 7.59-7.53 (m, 1H), 7.33-7.27 (m, 3H), 7.25-7.22 (m, 2H), 7.12-7.05 (m, 1H), 3.12 (s, 1H), 3.08 (s, 1H). HRMS (ESI): m/z calcd for C_9H_7NO $[M+H]^+$: 146.0600, found: 146.0605

N-formylbenzamide: CAS registry No. 4252-31-7



White solid; mp: 112.4~113.8 °C; 1H NMR (500 MHz, $DMSO-d_6$) δ 11.75 (s, 1H), 9.26 (s, 1H), 8.04-7.98 (m, 2H), 7.70-7.65 (m, 1H), 7.57-7.52 (m, 2H). HRMS (ESI): m/z calcd for $C_8H_7NO_2$ $[M+H]^+$: 150.0550, found: 150.0550

NMR spectra of final compounds

